# THE NICKEL BULLETIN

## A MONTHLY SUMMARY OF CURRENT INFORMATION

MAY, 1956


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# ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

## GENERAL

### Spring Materials: Specifications and Applications

H. C. R. CARLSON: 'Selection and Application of Spring Materials.'
*Amer. Soc. Mechanical Engineers*, Paper No. 55-A-76, Nov. 1955; 14 pp.

It has been observed that, in spite of much information which is already available on spring materials, incorrect and unsuitable specification requirements are often submitted to spring manufacturers. The author of this paper has therefore attempted, by means of tabular summary data, to indicate the properties and uses of the various types of material which are in common use for springs. Each table contains, for the respective materials covered, the numbers of the U.S. specifications governing supply, and notes on considerations which should dictate selection for individual applications. The groups of material so reviewed include:

High-Carbon Spring Steels;
Alloy-Steel Spring Steels;
Valve-Spring Steels;
Tool Steels used for Springs.
Stainless Spring Steels (chromium-nickel 18-8, 18-12-Mo, 17-7, and three grades of straight-chromium steel);
Copper-base Alloys (brass, bronzes, beryllium-copper, copper-manganese, nickel silver, cupro-nickel);
Nickel-base Alloys (Monel, K Monel, Inconel, Inconel 'X', Duranickel);
Flat High-Carbon Spring Steels;
Constant-Modulus Alloys (Elinvar, Ni-Span C, Isoelastic, Elgiloy, 8J Alloy, Durapower, Co-benium, Dynavar) all of which are nickel-iron base alloys containing one or more of the following elements: — chromium, titanium, molybdenum, cobalt.

Some 40 spring materials are represented in the survey.

### Nuclear Power Plant

'Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955, Vol. 2; Physics; Research Reactors.'
Published by *United Nations, New York*, 1956; 471 pp. Price 57/-.

This volume covers sessions 6A, 7A, 8A, 9A and 10A.1. The papers and discussions are presented in groups relating, respectively, to special topics in nuclear physics, fission physics, and research reactors, with descriptions of individual plants.

## NICKEL

### Geology of the Ores of the Levack Area, Sudbury, Ontario

G. P. MITCHELL and A. D. MUTCH: 'Geology of the Hardy Mine, Sudbury District, Ontario.'
*Canad. Mining and Metallurgical Bull.*, 1956, vol. 49, Feb., pp. 75-81; *Trans. Canad. Inst. Mining and Metallurgy*, 1956, vol. 59, pp. 37-43.

The authors describe the essential features of the geology of the Levack area, Sudbury, as shown in the Hardy mine of Falconbridge Nickel Mines, Limited. Attention is directed also to papers which have recently described other properties in the Sudbury area.

### Surface Optical Constants of Nickel and Other Metals

S. ROBERTS: 'Interpretation of the Optical Properties of Metal Surfaces.' *Physical Rev.*, 1955, vol. 100, Dec. 15, pp. 1667-71.

The surface optical properties of the metals silver, gold, copper, platinum, iridium and nickel, in the infrared, are shown to obey a simple generalized form of the Drude formula* for the free electron theory, but involving two types of free electron. Until now it has been generally believed that the optical properties of metals are influenced by an anomalous surface layer, but the evidence presented by the author gives rise to some doubt as to whether such a surface layer has any significant effect on the optical properties of metals in the infrared at ordinary temperatures. Evidence for and against the anomalous surface layer theory is critically reviewed.

### Spring Materials: Specifications and Applications

See abstract in left-hand column.

* Physikalische Zeitsch., 1900, vol. 1, p. 161.

### Raney-Nickel and Raney-Cobalt Catalysts

W. REEVE and J. CHRISTIAN: 'A Comparison of Raney-Nickel and Raney-Cobalt Catalysts for the Hydrogenation of Oximes.'

*Jnl. Amer. Chemical Soc.*, 1956, vol. 78, Feb. 22, pp. 860–1.

A study was made of the behaviour of the two types of catalyst, in the hydrogenation of six oximes. It was found that, in general, Raney cobalt produced primary amines of as high a purity and as good a yield as were produced with a Raney-nickel catalyst. In some cases Raney cobalt produced the best results in ethanol or dioxane solvent without addition of ammonia, whereas it was found that with Raney nickel it was frequently necessary to use an ammoniacal solvent to obtain the best results. With both the catalysts the nature of the solvent and the presence or absence of ammonia have an important bearing on the yield and purity of the primary amine obtained.

### Influence of Sorbed Gases on Catalytic Nickel

L. E. MOORE and P. W. SELWOOD: 'The Influence of Chemisorbed Gases on the Magnetization of Catalytically Active Nickel.'

*Jnl. Amer. Chemical Soc.*, 1956, vol. 78, Feb. 22, pp. 697–701.

Thermomagnetic measurements were used to study chemisorption on nickel-silica catalysts. It was found that nitrous oxide, oxygen, and carbon monoxide increase the magnetization of this highly dispersed nickel at room temperature, and that water vapour and hydrogen have the reverse effect.

The results are interpreted in terms of electron interaction between nickel and the adsorbate. Interpretation of the observations made with regard to hydrogen is dependent on the particle size of the nickel. Desorption of hydrogen in flowing helium was studied by determining increase in magnetization as a function of time. The effects of sintering the nickel and of changing the temperature of chemisorption were also investigated.

### Carbon Deposited from Carbon Monoxide on Nickel

L. J. E. HOFER, E. STERLING and J. T. MCCARTNEY: 'Structure of the Carbon Deposited from Carbon Monoxide on Iron, Cobalt and Nickel.'

*Jnl. Physical Chemistry*, 1955, vol. 59, Nov., pp. 1153–5.

Catalytic deposition of carbon from monoxide by the reaction $2CO \rightarrow C + CO_2$ is highly deleterious in several industrial processes. At atmospheric pressure the reaction takes place between 300° and 800°C. The Fischer-Tropsch process used for the synthesis of hydrocarbons is subject to this carbon deposition (which may lead to blockage of the reaction vessel and to deactivation and disintegration of the catalyst), ceramic brick linings containing iron undergo physical disintegration when exposed to carbon monoxide under suitable conditions of diffusion and temperature, and the reaction is involved also in blast-furnace operation. The authors direct attention to reports of investigations on the structure of carbon deposited by decomposition of carbon monoxide on iron under various conditions, but point out that no parallel data have previously been published with regard to nickel or cobalt. Their work was directed, therefore, to study of the morphology of the carbon deposits on all three metals.

Methods used for preparation of the nickel, cobalt and iron catalysts are described, and procedure for purification of the carbon monoxide is also detailed.

In general, when carbon monoxide reacts with iron or cobalt at temperatures below 225°C., and with nickel below 270°C., carbides of the respective metals are formed almost exclusively, but above these temperatures deposition of free carbon occurs. At various temperatures these carbides undergo reactions, transitions, and/or decomposition, and when carbon monoxide reacts with these metals at a high temperature, e.g., 390°C. (the temperature used in these experiments), free carbon, various forms of carbides, and the original metals may all be present. Their relative amounts will depend upon the experimental conditions (time, temperature, composition of gas, rates of flow, etc.).

Examination, by electron microscopy, of the carbon deposits formed on iron, cobalt and nickel at 390°C. showed that they occur in the form of filaments 0·01–0·2μ in diameter. The filaments of the deposits on iron are single solid strands: those on nickel appeared to consist almost entirely of 'tubules' or of untwisted bifilaments, while on cobalt the deposits exhibited both the form of solid filaments and of tubules or bifilaments. It was observed that most of the filaments contained dense nuclei of about the same diameter as that of the filaments in which they lay: such nuclei are found about midway from the ends of the corresponding filaments. The nuclei in the nickel deposits appeared to have crystalline faces, but these could not be positively identified: analysis by powder diffraction indicated the likelihood that these nuclei contain face-centred-cubic nickel metal and/or the hexagonal close-packed nickel carbide.

### Complexometric Determination of Nickel in Presence of Other Elements

H. FLASCHKA and R. PÜSCHEL: 'Complexometric Titration of Nickel in the Presence of Cobalt and Some Other Inorganic Cations.'

*Zeitsch. f. analytische Chemie*, 1955, vol. 147, pp. 354–60.

Details of procedure are given in *Chemical Abstracts*, 1956, vol. 50, Jan. 10, p. 105.

### The Effect of Nickel on Oat Plants

W. M. CROOKE and A. H. KNIGHT: 'The Relationship between Nickel-Toxicity Symptoms and the Absorption of Iron and Nickel.'

*Ann. Applied Biology*, 1955, vol. 43, pp. 454–64; 465–76.

Main findings are reported in *Chemical Abstracts*, 1956, vol. 50, Feb. 10, p. 1987.

# ELECTRODEPOSITION AND OTHER COATING METHODS

### Mechanism of Levelling in Electrodeposition

H. LEIDHEISER: 'The Mechanism of Levelling during the Electrodeposition of Nickel in the Presence of Organic Compounds.'

*Zeitsch. f. Elektrochemie*, 1955, vol. 59, pp. 756–65.

The paper contains results obtained in a section of an extensive research sponsored by the Harshaw Chemical Company, Cleveland, Ohio. Attention is directed to four earlier papers which provide a background to the work now reported.

It has been found that one method by which levelling* can be effected is by the addition of specific organic compounds to the Watts-type nickel-plating solution: this is discussed in some of the earlier literature to which reference is made by the author.

The section of the work covered in the present paper was planned (*a*) to study the mechanism of levelling, and (*b*) to correlate the structure of organic compounds with their ability to produce levelling. The experiments were conducted in five groups, dealing respectively with, (1) deposition on sharp tips, (2) deposition over isolated scratches and projections, (3) deposition on wires of different diameter, (4) effect of variables on the rate of levelling in coatings from a commercial bath, (5) the relation of levelling to the cathode potential.

Steel piano wire and wire of a copper-silver alloy were used as the basis materials. The plating solutions employed were of the following types:—

| | | *g./L.* |
|---|---|---|
| (*a*) Watts solution | $NiSO_4.6H_2O$ | 240 |
| | $NiCl_2.6H_2O$ | 45 |
| | $H_3BO_3$ | 30 |

(*b*) The Perflow bath—

A proprietary process, developed by the Harshaw Chemical Company, for the production of semi-bright nickel deposits characterized by considerable levelling action.

(*c*) The modified XXX bath—

A proprietary process, also developed by Harshaw Chemical Company, for preparation of fully-bright nickel deposits.

In most of the tests the experimental conditions were as follows:—current density 4 amp./sq. dm.; pH 4·0; no stirring; temperature 60°C.

In experiments with the Perflow bath, however, the effect of variations in current density, pH, and temperature, on scratch-filling capacity, was determined. Full details are given of the experimental conditions, and the levelling produced in the respective tests is illustrated by a large number of photomicrographs showing scratch silhouettes obtained.

The results of the various series of tests show that in deposition from the Watts bath to which organic reagents had been added the rate of scratch-filling increased with an increase in the polarization of the cathode. In the commercial Perflow bath the rate of levelling increased as (1) the pH was increased, (2) the current density was decreased, (3) the temperature rose, and (4) the width of the scratch was decreased at a constant depth.

A proposed explanation of the mechanism of levelling is based on the migration of nickel ions or nickel atoms over the surface.

* Levelling comprises the filling of scratches and the reduction of the height to which raised areas project above the geometrical surface.

### Bright Nickel Plating: The Nimax Process

'Bright Nickel Process.'

*Metal Industry*, 1956, vol. 88, Mar. 9, pp. 187–8.

To meet the requirement for a nickel coating providing good mechanical properties combined with effective surface levelling and high brilliance, an improved plating process has been developed by Messrs. W. Canning and Company, Ltd., Birmingham. A single addition agent, Sylax, confers both brightening and levelling properties, and it is claimed that the solution is easily maintained. The new process is suitable for plating on both ferrous and non-ferrous materials. The solution may be used in rubber-lined bright-nickel-plating equipment: it is operated at 120°–130°F. (48°–55°C.), at a current density of 36–60 amp. per sq. ft. The relatively high pH (4–4·5) minimizes solution of any exposed unplated metal, and thus lessens contamination of the bath. It is claimed that throwing power and covering capacity are good, over a wide plating range: the levelling and scratch-filling obtained reduces the initial polishing required, and the deposit has the further advantage that it is free from surface passivity, permitting direct chromium plating without preliminary surface activation. In a large number of tests the deposits made have consistently shown an elongation of over 12 per cent., and relatively low internal stress, features which are of particular importance in the plating of components which have to undergo further fabrication after plating.

### Tin-Nickel Flashing of Die Castings Prior to Nickel+Chromium Plating

'Chromium Plating Tin-base Die Castings.'

*Metal Industry*, 1956, vol. 88, Mar. 23, p. 229.

Abstracted from *Tin and Its Uses*, 1956, Jan., pp. 4, 16.

The report gives details of difficulties experienced due to peeling of copper+nickel+chromium-plated tin-base die castings.

Although, immediately after plating, the coatings showed satisfactory adherence to the basis metal, after only a week of storage peeling was observed. The normal thickness of copper flash being applied before nickel plating was of the order of 0·000006 in. and it was found that with such thin coatings the copper rapidly diffused completely into the tin-alloy base. Even with somewhat thicker copper underlays diffusion had led to breakdown of the bonding layer between the base casting and the coating, and, within a short period, the nickel-chromium coating

had become nothing more than a non-adherent envelope.

Experiments in which nickel was plated direct onto the tin-base alloy (without copper undercoat) gave less satisfactory adhesion immediately after plating than those which had been coated by the normal procedure, but there was no deterioration in adhesion after storage for a year.

The problem was overcome by adoption of a thin-flash treatment with 65-35 tin-nickel alloy, after which nickel+chromium plating was carried out in the usual manner. Adhesion of coatings of this type proved entirely satisfactory.

In connexion with the faulty adhesion resulting from diffusion of copper into the tin alloy, the following comment is made:—

'This experience is a confirmation of the difficulty which is often encountered in the electrical industry when soldering tin-plated copper wires or tags, and poor adhesion is noticed, sometimes after storage for a period of a few weeks only. It is now recommended practice to plate all copper and brass soldering tags with a thin flash of nickel (0·00005 in., 0·00125 mm.) as a protection against deterioration of the tin coating during storage. The nickel flash is recommended not only for electrodeposited tin coatings, but also for hot-dip coatings, because although these seldom give difficulty in soldering after storage, the nickel coating is an effective barrier during dipping and prevents undue dissolution of copper or brass in the molten tin or solder.'

### Metal Finishing Handbook

I. S. HALLOWS (Editor): 'Finishing Handbook and Directory' 6th Edn., 1956.

Published (for *Product Finishing*) by *Sawell Publications, Ltd., London*, 1956; 489 pp.

This edition of the handbook has been amplified by addition of new sections, (e.g., dealing with correction of faults in plating baths and with the treatment of plating wastes). Established sections containing both technical and trade information have been completely revised. Part I (technical) opens with a section on treatments used in preparation for coating of metals, and contains chapters dealing with application and uses of paints, and of metallic, chemical, enamel, plastic and other types of finish. Section II (directory) contains information on suppliers of equipment, plant and materials, out-workers' services, trade names of materials and processes, and names and addresses of firms associated with the metal-finishing industry.

## NON-FERROUS ALLOYS

### Forming and Shaping of Non-Ferrous Metals and Alloys: Symposium

A symposium on the Final Forming and Shaping of Wrought Non-Ferrous Metals was arranged as part of the programme for the Annual Meeting of the Institute of Metals, held in London in April, 1956. Papers presented are published in the February and March issues of the *Journal*, see below:—

D. F. GALLOWAY: 'The Machining Properties of Non-Ferrous Metals.'

*Jnl. Inst. Metals*, 1955-56, vol. 84, Feb., pp. 121-31.

During the Second World War developments in the aircraft field stimulated interest in the machining of non-ferrous alloys. The demand for higher rates of metal removal, better surface finish, closer accuracy of dimensions, etc., gave rise to significant improvements in machines and tools, and also indicated an urgent need for further research to determine optimum combinations of speed, feed, cutting angles and other variables. During that period, and particularly in more recent years, the increasing application of high-strength materials such as the Nimonic alloys and titanium-base alloys has presented new problems, and it is the techniques which have been developed for study of these problems, together with some typical results of research, which form the subject of this paper.

Introductory notes on criteria used to assess machinability and machining performance are followed by a detailed description of experimental apparatus employed for measurement of cutting forces and tool shape. The variation in the machining characteristics of non-ferrous materials is demonstrated by comparison of cutting forces for a range of typical metals and alloys. The combined effects of cutting speed and feed rate, on tool life, are shown in a series of charts, which also indicate optimum cutting conditions for various materials. The paper includes results of experiments carried out to determine variations in surface finish in relation to cutting speed, feed, material of the cutting tool, and orientation of a faceted diamond tool. The materials used in the experiments reported included aluminium alloys, Nimonic 80 (precipitation-hardened nickel - chromium - base alloy), titanium - base alloys and some bronzes. In some of the tests comparison is made with various steels.

The concept of machinability expressed in terms of a single rating or index obtained from so-called machinability testers is discussed, and it is shown that the validity of simplified machinability tests in production practice is contingent on there being sufficient evidence of adequate correlation between the results of the tests and performance under production conditions.

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J. A. GRAINGER: 'The Deep Drawing and Spinning of Sheet Metal, with Particular Reference to Non-Ferrous Materials', *ibid.*, pp. 133-46.

Recent developments in machines and methods for deep drawing and for spinning of sheet are reviewed, with particular reference to techniques evolved to secure satisfactory results on an economic basis. Deep drawing is considered in relation to drawing of cylindrical shells, and of complex shapes, the design of drawing presses is described, and methods used for testing the efficiency of lubricants are reviewed. A report is made of deep-drawing

tests made on sintered aluminium powder, and on Nimonic 75. The conclusion reached is that 'S.A.P. has very little capacity for being deep drawn and if pressings are required in this material considerable experimental and development work will need to be carried out to perfect a suitable technique.' A detailed report on the experiments on Nimonic 75 gives results of deep-drawing of specimens with and without a (proprietary) surface oxylate pre-treatment, and using four different types of lubricant: (a standard drawing oil, molybdenum disulphide as powder, a suspension of molybdenum disulphide in a synthetic carrier, and the drawing oil with a 2 per cent. addition of molybdenum disulphide). From the results it is concluded that, provided that the material is surface treated in the way described and that extreme-pressure lubricants of suitable type are used, Nimonic 75 sheet can be subjected to far more severe reductions during deep drawing than is the practice at present. In these tests overall reduction of 53 per cent. (blank to final pressing) was achieved in two draws with one inter-stage anneal, and the product showed properties equal to those of control material subjected to four drawing operations with three inter-stage annealing treatments.

The latter part of the paper is devoted to a description of the salient features of Marforming and Hydroforming processes for drawing, and of spinning techniques, including Flowforming.

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J. FIELDING: 'Rubber Pressing', *ibid.*, pp. 147–59.

The reasons for adoption of rubber pressing in forming of light-alloy aircraft components are discussed, and methods and equipment for forming aluminium and magnesium alloys and titanium are described. The merits of 'cold' and 'hot' forming of magnesium alloys and of titanium are considered, and details are given of hot-pressing techniques, with special reference to die materials, temperatures, pressures, and the use of heat-resisting rubbers.

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W. JOHNSON: 'Research into Some Metal-Forming and Shaping Operations', *ibid.*, Mar., pp. 165–79.

An account is given of some results obtained in experimental and theoretical investigations carried out at Sheffield University into the drawing and redrawing of cylindrical shells with hemispherical and flat-headed punches, with particular reference to the effects of lubrication, drawing speed, and flange wrinkling; ironing; tube-sinking; detection and measurement of residual stresses in cold-drawn tubes; impact-extrusion under a drop hammer; coining. Attention is also directed to problems still outstanding in these fields.

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E. GRIFFIN: 'Cold Roll-Forming and Manipulation of Light-Gauge Sections', *ibid.*, pp. 181–97.

The author outlines the advantages of cold forming as a method for large-scale production of sections of complicated profile, from strip. The forming process itself is described in detail, with discussion of the types of machine used and their capacities, calculation of power requirements, and the design and manufacture of roll-forming tools. The operation of cold-roll-forming machines is also dealt with and the use of press brakes for forming simple sections is considered.

The manipulation of cold-roll-formed sections is described and details are given of finishing procedures used in production of aluminium-alloy slatting for Venetian blinds.

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R. D. EDWARDS: 'Stretch-Forming of Non-Ferrous Metals', *ibid.*, pp. 199–209.

A brief account of the theory of stretch forming is followed by a detailed description of machines and methods employed for stretch-forming of aluminium-alloy sheets, extrusions, and other sections, used mainly in the aircraft industry. Some examples of stretch-formed components are illustrated.

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T. G. PERRY: 'Bending and Allied Forming Operations', *ibid.*, pp. 211–16.

The metallurgical factors involved in plain bending, tube bending, flanging, and rolling are discussed. The concept of the strain-hardening exponent is used to provide empirical relationships for rolling-machine capacities, and for buckling criteria in bending.

The paper includes the values of the strain-hardening component, n, for 18–8 chromium-nickel steel, Monel, brass, copper, and several types of aluminium alloy.

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R. G. WILKINSON: 'The Hot Forming of Magnesium Alloys', *ibid.*, pp. 217–28.

Magnesium-base alloys, having a close-packed hexagonal crystal lattice, are capable of only limited cold deformation. Unless the work is very simple, they are therefore usually formed at elevated temperatures, a practice which, although suffering from some operational disadvantages, has important compensating features. In this paper the compositions and mechanical properties of the principal commercial wrought magnesium alloys are given, the effects of heating, on their properties, are discussed, and an account is given of some special requirements which must be satisfied with regard to equipment and technique for hot-forming sheet and extrusions.

### Hall Coefficients of Nickel-Copper Alloys

F. E. ALLISON and E. M. PUGH: 'Temperature Dependence of the Two Hall Coefficients in Three Copper-Nickel Alloys.'

*Bull. Amer. Physical Soc.*, Ser. II, 1956, vol. 1, Mar. 15, p. 115.

Abstract of paper to American Physical Society, Mar., 1956.

The two Hall coefficients and the resistivity of nickel-copper-alloys containing 80, 70 and 60 per cent. of nickel were measured over the range 4° to 400°K. (−269° to +127°C.).

### Electrical Resistivity of Nickel-Palladium Alloys

A. I. SCHINDLER, R. J. SMITH, and E. I. SALKOVITZ: 'Electrical Resistivity of Nickel-Palladium Alloys.'
*Bull. Amer. Physical Soc.*, Ser. II, 1956, vol. 1, Mar. 15, p. 114.
Abstract of paper to American Physical Society, Mar., 1956.

The electrical resistivity of alloys in the palladium-rich side of the system was examined, as a function of temperature 77° to 320°K. (−196° to +47°C.). It is noted that 'the data at 77°K. and 293°K. (−196° and +20°C.) both exhibit the same general behaviour. The electrical resistivity increases slowly as palladium is added to nickel, reaches a maximum in the vicinity of 70 at. per cent. palladium and then falls rapidly to the pure palladium value. This shape is similar to the appearance of the electrical resistivity *vs.* composition curve of the silver-palladium alloy series.'

### Nickel-Doped Germanium

J. F. BATTEY and R. M. BAUM: 'Carrier Capture Probabilities in Nickel-Doped Germanium.'
*Physical Rev.*, 1955, vol. 100, Dec. 15, pp. 1634–7.

Nickel was diffused into germanium in order to study the carrier capture probabilities of the two nickel-acceptor levels, one of which had been found to occur at 0·22 ev above the top of the valence band, the other at 0·30 ev below the bottom of the conduction band.

### Titanium and Titanium Alloys: Textbook

A. D. McQUILLAN and M. K. McQUILLAN: 'Titanium.' Published by *Butterworths Scientific Publications*, 1956; 466 pp. Price 56/-.

The book is the fourth of a series dealing with the metallurgy and properties of the rarer metals. The first three volumes covered, respectively, chromium, zirconium, and manganese. The aim of the series is to provide readable works of reference covering metallurgical, chemical and physical data on the metals, together with sufficient historical background to permit full appreciation of the specialized information.

In the volume now published a full account is given of the basic properties of titanium and its alloys, with some account of the principles involved in all aspects of production and processing of the metal. The early chapters deal with history and occurrence, recovery of titanium from its ores, industrial production, melting and casting, and fabrication technique: these are followed by detailed treatment of the constitution of titanium-containing alloys, and transformations occurring in such materials. Later chapters are concerned with the mechanical properties of titanium and titanium-rich alloys, the reaction of gases with the metal and its corrosion-resisting characteristics. The closing chapter contains a summary of information on metallographic techniques for use on titanium, with details of typical structures. All sections of the book are supplemented by *bibliographies* correlated with the text.

The titanium-nickel system is discussed, with diagrams, and attention is directed to the suitability of titanium-nickel-base alloys as brazing materials.

## CONSTRUCTIONAL STEELS

### Ultra-High-Tensile Steels

K. J. IRVINE: 'Ultra-High-Strength Steels.'
*Aircraft Production*, 1956, vol. 18, Mar., pp. 84–9.

The author discusses problems involved in the use, e.g., in aircraft construction, of steels of the 100–150 ton tensile range. Factors which have militated against immediate confidence in such steels are reviewed, with due consideration of the difficulties of ensuring adequate toughness, consistency of properties, and sufficiently high fatigue-resistance. Data illustrating properties typical of ultra-high-tensile steels support the discussion.

It may be accepted that strength levels of the order mentioned will not be attained without some sacrifice of toughness, but it is possible, by adjustment of composition and treatment, to achieve a combination of properties which, while including an acceptable level of toughness, will permit utilization of increased tensile strength. The main part of this paper is devoted to a demonstration of methods by which such combination of strength and toughness can be secured: particular attention is directed to control of carbon content and to selection of suitable tempering temperatures. Data on the properties of low-alloy steels having carbon contents ranging from 0·25 to 0·45 per cent. and containing varying amounts of chromium, nickel-chromium or nickel-chromium-molybdenum are graphically presented, and the observations made are correlated with findings reported in the literature.

From the results described, and consideration of other available information on ultra-high-tensile steels of various compositions, it is concluded that the following general principles can be laid down as basic for production of a specially high level of tensile strength, combined with toughness which will be adequate to ensure safe usage of the steels in critical engineering applications:—

The steel should have, in the quenched condition, a 100-per cent. martensite structure.
Consideration of the tempering characteristics of low-carbon martensitic steels and of the properties obtainable in the tempered condition indicates that the carbon content of ultra-high-tensile steel should be as low as is consistent with the required level of tensile strength.
In tempering, it is essential to avoid treatment in an embrittling range.

Particular reference is made to the suitability of a nickel-chromium-molybdenum steel (1·5–2/1·75/0·25 per cent. approx.) to meet specification requirements.

It is emphasized that at the present stage of development the ultra-high-tensile steels must be used with caution, but that prospects appear promising for steels of the 100–140 ton tensile range, and that there is also a possibility of more widespread use of low-carbon-martensite steels at the 80–110 tons per sq. in. level.

### Influence of Alloy Elements on Case-Hardening Characteristics

H. U. MEYER: 'The Influence of Alloys on the Surface Hardenability of Case-Hardening Steels.'

*Stahl und Eisen*, 1956, vol. 76, Jan. 26, pp. 68–77; disc., pp. 77–8.

Report of an investigation on the effect of carbon and alloy elements on (1) maximum surface hardness attainable, and (2) depth of hardness penetration. The steels used were selected from standard American and German carburizing steels, supplemented by experimental steels. Twelve of the compositions used were chosen as being of medium hardenability, and eleven were of higher hardening capacity.

### Spring Materials: Specifications and Applications

See abstract on p. 84.

### Corrosion by Fertilizers

See abstract on p. 97.

### Weldability of Manganese-Nickel-Chromium-Molybdenum Steels

C. L. M. COTTRELL, B. J. BRADSTREET and T. E. M. JONES: 'The Weldability and Mechanical Properties of a Series of Mn-Ni-Cr-Mo Steels.'

*Brit. Welding Jnl.*, 1956, vol. 3, Mar., pp. 90–8.

An earlier report had covered examination of the susceptibility to hard-zone cracking of a series of low-alloy manganese-nickel-chromium steels welded by the metal-arc process, using rutile-coated electrodes conforming to B.S.1719, Class E.217 (see *Jnl. Iron and Steel Inst.*, 1951, vol. 169, Dec., pp. 321–36; abstract in *Nickel Bulletin*, 1952, vol. 25, No. 2, p. 47). As a result of that work, two compositions were selected for further study, and both gave satisfactory welding properties (as assessed by the Reeve test on welds made with rutile-coated electrodes in plates of 1½-in. thickness). The 0·5 per cent. proof stress of the plates was, however, only 23 tons per sq. in. in the normalized condition and 25–28 tons per sq. in. after normalizing and tempering.

Later tests were therefore designed to determine the crack-sensitivity of the more highly-alloyed steels of the original series, when welded with low-hydrogen electrodes. The aim was development of steels which would combine a much higher proof stress with good weldability. The work is described in this paper. The steels used for tests were planned to obtain systematic variation in carbon, manganese, nickel and chromium contents, and the effects of welding were evaluated by the 'controlled-severity test' developed by the British Welding Research Association.

The effect of changes in composition, on weldability within the range selected, was expressed in the form of diagrams which were compared with other diagrams illustrating the effect of variation in composition on the 0·3 per cent. proof stress, measured on similar materials in two section thicknesses. Such interrelation permitted choice of steels which would give optimum combination of weldability and mechanical strength. Confirmatory tests on steels of compositions thus selected were carried out; dilatation tests were also made, and a continuous-cooling diagram was constructed.

The investigation has led to the recommendation of two compositions which will give a minimum proof stress of 35 tons per sq. in. in the normalized condition in 1½-in. thick plate, and will show good weldability when low-hydrogen electrodes are used. The compositions of the steels are shown below:—

| C % | Mn % | Ni % | Cr % | Mo % |
|---|---|---|---|---|
| 0·11-0·15 | 1·5-1·8 | 0·6-0·8 | 0·7-0·9 | 0·2-0·25 |
| 0·11-0·15 | 1·1-1·4 | 1·0-1·2 | 0·9-1·1 | 0·2-0·25 |

The tests thus show that the best combination of weldability and strength is obtained in a multiple alloy steel of low carbon content.

Observations have also been made with regard to the safe limit of maximum hardness in the heat-affected zone of low-alloy steels.

### Metallurgical Factors in the Welding of Steels

See abstract on p. 98.

## HEAT- AND CORROSION-RESISTING MATERIALS

### Vacuum Melting of High-Temperature Nickel-base Alloys

F. N. DARMARA and J. S. HUNTINGTON: 'Experiences in Production Vacuum Melting of Nickel-base Alloys.'

*Amer. Soc. Mechanical Engineers*, Paper No. 55-A-198; 8 pp. + figures.

The author describes production experience in the Metals Division of the Utica Drop Forge and Tool Corporation, showing the consistency with which vacuum-melted alloys may be produced in large quantities to close specification. Plant now in use is described and illustrated, and production technique is detailed, with discussion of practical operating problems.

Experience in vacuum melting in the Utica plant has been concerned mainly with high-temperature alloys for turbine blading and other components of jet engines for aircraft. Most of the alloys have

been nickel-base, containing varying amounts of chromium, cobalt, molybdenum, with or without titanium and aluminium. As a specific example of the results obtainable by vacuum processing, a report is made on production of Waspaloy, an alloy of the following composition:— chromium 18–20, cobalt 12–15, molybdenum 3·5–5, titanium 2·75–3·25, aluminium 1·0–1·5, iron 2·0 max., manganese 1·0 max., silicon 0·75 max., sulphur 0·03 max., carbon 0·10 max., per cent., nickel remainder. This alloy, in the form of forged turbine blades, was required to meet a stress-rupture specification of more than 40-hours' life at 1500°F. (815°C.) under a stress of 32,500 p.s.i. (14·5 tons per sq. in.), and considerable difficulty was found in consistently satisfying this requirement in air-melted material. Vacuum melting, however, has resulted in a three-fold improvement in life to rupture. Testing is now being done with a stress of 40,000 p.s.i. (17·85 tons per sq. in.) at 815°C., and a survey of tests on some 40 recent representative heats shows an average life of 74 hours, with a scatter range of 56 to 90 hours in these conditions. Elongation averages 18 per cent. It is considered that one of the major factors responsible for this marked improvement in properties is the possibility afforded by vacuum melting for holding the aluminium and titanium contents within limits much closer than those obtainable in air melting. A further significant feature is the greater general cleanliness brought about by removal of dissolved gases, reduction of oxides, nitrides, and sulphides, and the evaporation of volatile impurities. The conclusions drawn from experience with Waspaloy are supported by similar results in the vacuum melting of M-252 and other nickel-base alloys. It is reported that in every case a decided improvement has been obtained in stress-rupture life and ductility.

While it is agreed that for many applications the degree of control secured by vacuum melting is an unnecessary refinement, the authors urge, on the basis of the large-scale experience already available on a limited number of alloys, that 'there are a large number of applications in which air-melting methods cannot give the consistency required, and that it is in this field that vacuum melting can be of the greatest benefit. This technique is providing a new means of obtaining the maximum properties possible from known alloys, and of developing new alloy systems on a production basis.

**Nickel-base Forging Alloys for High-Temperature Service**

'Forging Alloys for High-Temperature Service.' *Metal Industry*, 1956, vol. 88, Mar. 23, pp. 225–6.

This note is abstracted from a paper recently presented to the Society of Automotive Engineers. It reports a study of material from single heats of four high-temperature alloys suitable for precision-forged gas-turbine blading. Compositions and heat-treatments suitable for the alloys are shown in the tables on page 92.

The following observations are made on the results of the tests reported.

*Tensile Properties*

The tensile strength of Udimet 500, M-252 and INCO 700 is greater than that of S-816 between 540° and 925°C., but the difference begins to narrow as the temperature rises, and at 1095° and 1150°C. S-816 is stronger than the other three alloys. Between 540° and 870°C. the three higher-strength alloys show the lowest elongation values, but between 1080° and 1150°C. S-816 has the lowest elongation: the other three alloys elongate rapidly, in some cases too quickly to permit measurement.

*Stress-Rupture Properties*

Bar stock of Udimet 500 and INCO 700 showed the best stress-rupture life at 815° and 900°C., but both were characterized by the lowest ductility at these temperatures. At 815°C. M-252 combines good life with satisfactory ductility.

*Forging*

The forging-temperature ranges for the four alloys are shown in the following table:—

| Alloy | Starting Temperature (°C.) | Finishing Temperature* (°C.) |
|---|---|---|
| S-816 .. | 1150 | 870 |
| M-252 .. | 1095 | 955 |
| Udimet 500.. | 1095 | 1040 |
| INCO 700 .. | 1095 | 980 |

* Indicates finishing temperature in the dies.

In all cases the alloys are susceptible to grain growth, and close control of forging temperatures is therefore necessary: the nickel-base alloys are more prone to differential grain growth than are the cobalt-base type, and must therefore be forged within a narrower temperature range. The extremely limited forging range for Udimet 500 is necessitated by its high temperature of recrystallization and its liability to work-hardening. It is noted that at the high temperatures employed for forging and heat-treatment the nickel-base alloys are susceptible to superficial intergranular attack to a depth of about 0·002 in., and that a cold-worked surface may be produced during grinding operations. In both cases the surface effects may be removed by electrolytic pickling.

*Melting*

S-816 and INCO 700 are melted by conventional methods, but M-252 and Udimet 500 are vacuum-induction melted, and M-252 has also been vacuum melted by the consumable-electrode process. It has been observed that the overall properties of the vacuum-melted M-252 are superior to those of the same alloy melted in air, and it is believed that the full potential improvement in consistency obtainable, in this and other alloys, by vacuum melting has not yet been fully explored.

**Compositions of Alloys Tested**

| Alloy | C % | Co % | Ni % | Cr % | Mo % | W % | Nb % | Ti % | Al % | Fe % |
|---|---|---|---|---|---|---|---|---|---|---|
| S–816 .. .. | 0·40 | 42 | 20 | 20 | 4 | 4 | 4 | — | — | 4 |
| M–252.. .. | 0·15 | 10 | 53 | 19 | 10 | — | — | 2·5 | 0·75 | 4 |
| Udimet 500 .. | 0·10 | 14 | 55 | 19 | 4·25 | — | — | 3 | 3 | 1 |
| INCO 700 .. | 0·10 | 28 | 48 | 15 | 3 | — | — | 2·5 | 2·5 | 1 |

**Heat-Treatment of Alloys Tested**

| Alloy | Solution Treatment | | | Ageing Treatment | | |
|---|---|---|---|---|---|---|
| | Temp. (°C.) | Time (hrs.) | Quench Medium | Temp. (°C.) | Time (hrs.) | Quench Medium |
| S–816 .. | 1177 | 1 | Water | 760 | 12 | Air |
| M–252 .. | 1066 | 4 | Air | 760 | 15 | |
| Udimet 500 | 1080 | 4 | Air | 843 | 24 | |
| | | | | 760 | 16 | |
| INCO 700.. | 1177 | 2 | Air | 871 | 4 | |

**Creep and Fracture at High Temperatures: Symposium**

NAT. PHYSICAL LABORATORY: 'Creep and Fracture of Metals at High Temperature.'

Proceedings of Symposium held May 31–June 2, 1954.

Published by *Her Majesty's Stationery Office*, 1956; 419 pp. Price £1 10s. 0d.

A résumé of the papers appeared in *Metallurgia*, 1954, vol. 50, Aug., pp. 81–6.

An introductory paper dealing with relevant work at the National Physical Laboratory is followed by twenty-one papers and discussion on specific aspects of creep and fracture. The contributions are arranged in four sections, concerned, respectively, with deformation processes in simple materials, creep-resistance of complex materials, theory of fracture, and tertiary creep and fracture. Appendices contain lists of authors' names, and of those who attended the meeting.

**American High-Temperature Alloys: Composition and Properties**

'Approximate Strength of Industrial Gas-Turbine Alloys Treated for Optimum Properties.'

*Metal Progress*, 1956, vol. 69, Feb., p. 80B.

Tabular summary of tensile, stress-rupture and creep characteristics, at various temperatures, for the materials listed below. The lower limit of the range covered is in all cases 70°F. (20°C.): the upper limits vary from 1200° to 1800°F. (650° to 980°C.) according to the material.

19–9 *D.L.* Complex 18–8 type chromium–nickel steel.

*A.I.S.I. Type* 321. Chromium–nickel stainless steel (titanium–stabilized).

*A.I.S.I. Type* 347. Chromium–nickel stainless steel (niobium–stabilized).

*A.I.S.I. Type* 410. 12 per cent. chromium steel.

*S*-590. Complex cobalt–chromium–nickel–iron–base alloy.

*N*-155 *Multimet.* (Low-carbon grade.)

*Haynes Alloy* 21. (Vitallium) cobalt–base alloy.

*Timken* 17–22 *A.S.* (*Cyclops* 14 *M.V.*) Chromium–molybdenum–vanadium steel.

*Timken* 16–25–6. Chromium–nickel–molybdenum steel.

*A.C.I. Alloy Type H.T.* 35–15. Nickel–chromium–iron alloy.

**Cobalt-Chromium-Tungsten-Nickel High-Temperature Alloy**

SOC. AUTOMOTIVE ENGINEERS: 'Alloy, Corrosion- and Heat-Resistant.'

*A.M.S. Specification* 5759, issued Feb. 1, 1956.

Covering bars, forgings and forging stock primarily for parts requiring high strength up to about 1500°F. (815°C.) and oxidation-resistance up to 2000°F. (1095°C.).

*Composition*, %: Carbon 0·05–0·15, silicon 1·00 max., manganese 1·00–2·00, sulphur 0·030 max., phosphorus 0·040 max., chromium 19·00–21·00, nickel 9·00–11·00, tungsten 14·00–16·00, iron 3·00 max., cobalt remainder.

Tensile and stress-rupture requirements are laid down, for the material in the solution-treated condition.

## Oxidation-Resistance of Molybdenum Alloys

G. W. P. RENGSTORFF: 'Search for Oxidation-Resistant Alloys of Molybdenum.'

*Jnl. of Metals*, 1956, vol. 8, Feb., Sect. II; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 171–6; T.P. 4030E.

This paper reports another research carried out with the object of finding alloys in which it should be possible to utilize the high-temperature strength of molybdenum without occurrence of the deterioration, due to the 'catastrophic oxidation', to which molybdenum-containing materials are subject at temperatures above about 1450°F. (785°C.). Although no alloy examined offered the requisite degree of resistance to oxidation, the information obtained with regard to the effect of a large number of elements on the oxidation of molybdenum will, it is believed, prove useful in the development of oxidation-resistant coatings.

The choice of the alloys to be investigated was based on the following considerations:—

Alloying elements might be expected to protect molybdenum in either of two ways: (1) their oxides might combine with molybdenum oxide to form a stable non-volatile complex oxide (a molybdate), or (2) the oxide of the alloying element might form in preference to molybdenum oxide, developing an impervious layer which would prevent formation of volatile molybdenum oxide.

The initial study was made on alloys of molybdenum-containing elements which have specially stable oxides. On this basis binary and ternary alloys containing the following six elements were investigated:—aluminium, chromium, titanium, zirconium, silicon and vanadium. Nickel was also added as an alloying element, and these alloys proved to be the most promising of those tested in the first screening experiments. Because nickel was effective in reducing oxidation rate, the elements iron, cobalt and tungsten were added to the list. The ten alloying elements mentioned formed 10 binary and 45 ternary systems with molybdenum; all of these were subjected to oxidation tests. In addition at least one test was made to evaluate the effect of the following elements:—boron, boron+iron, platinum, copper, lead, thorium, beryllium, tin, antimony, manganese, lithium, magnesium, zinc, silver, bismuth and calcium.

The results of the tests recorded indicate that it is unlikely that it will be possible to develop any molybdenum-base alloy which, at 1800°–2000°F. (980°–1095°C.) will have high oxidation-resistance combined with the good mechanical properties characteristic of unalloyed molybdenum. At least 15 per cent. of nickel, or 25 per cent. of chromium, was required to lower the oxidation rate of molybdenum by a factor of 100, and even this reduced rate is not sufficiently low to be acceptable for service at high temperatures in air. Further, the high alloy contents required to secure appreciable decrease in oxidation deleteriously affect the mechanical properties of molybdenum. It thus appears that the solution of the problem must be sought by cladding or coating.

The oxidation rate of molybdenum is greatly reduced by addition of calcium: a molybdenum compact impregnated with 8·7 per cent. calcium had about the same oxidation rate as an alloy containing 15 per cent. of nickel. The physical properties of the compact were, however, poor, and the reduction in the rate of oxidation is not sufficiently great to justify consideration of such material for coatings. Nevertheless, it would appear that lime or calcium molybdate might usefully be employed to prevent excessive losses of molybdenum by oxidation when it is heated to high temperatures in air for fabrication.

It is noted that the reduction in oxidation rate resulting from addition of nickel, and formation of a nickel molybdate coating, confirms the work of SPRETNAK (see *Nickel Bulletin*, 1956, vol. 29, No. 3, p. 45). The present authors therefore support the view that the use of nickel as an alloying element is worthy of further study.

## Influence of Sulphate-Chloride Mixtures in Fuel-Ash Corrosion at High Temperatures

H. T. SHIRLEY: 'Effects of Sulphate-Chloride Mixtures in Fuel-Ash Corrosion of Steels and High-Nickel Alloys.'

*Jnl. Iron and Steel Inst.*, 1956, vol. 182, Feb., pp. 144–53.

Concern with regard to 'the vanadium-pentoxide problem' has tended to obscure the importance of sulphate-chloride compounds, which in 1951 had been reported as causing rapid increase in rate of scaling in austenitic steels (see *Iron and Steel Inst. Special Report* No. 43, pp. 153–61). Recently, however, tests on equipment burning non-vanadium fuels have shown that the rôle of sulphate-chloride mixtures is one requiring careful consideration. In certain gas turbines, attack by peat ash has indicated that in some circumstances serious corrosion might thus be produced on both high-alloy steels and nickel-base alloys.

Preliminary tests, on two steels and on the nickel-chromium alloy Nimonic 80A, after operation for 1,000 hours at 770°C. with peat fuel, showed severe attack, associated with sulphur pick-up averaging 0·5 per cent. in the first few thousandths of an inch from the surface. This observation, supported by other confirmatory evidence, led to further investigations.

The main work reported comprised a series of tests on cylinder specimens of the two austenitic chromium-nickel steels and Nimonic 80A. In some of the experiments chromium, nickel, mild steel, straight-chromium steel, 25 per cent. nickel steel, and other high-nickel-chromium iron alloys were also used. The tests covered study of the effects of variations in salt mixture on attack at 750°C. in air, of the influence of pre-heating of the corrosive mixtures, of variation in the material of the vessels in which the tests were made, of temperature, of composition of test metals and alloys, and of the structural effects associated with the various forms of attack. The following main conclusions are drawn:—

The results of the tests confirm the possibility of

the severe attack on heat-resisting steels and nickel-chromium alloys which has been observed, under service conditions, in both peat- and oil-burning equipment. Laboratory tests have indicated that such attack is not related to direct sulphur absorption from gaseous combustion products, but that it occurs through contact with chloride-contaminated alkali and alkaline-earth sulphates, as little as 1 per cent. chloride inducing a high rate of attack at 700°-750°C. In order to determine whether sodium-sulphate/vanadium-pentoxide mixtures were also liable to cause similar sulphur-penetration attack, tests were made, at 750°C., on Nimonic 80A, in (*a*) vanadium pentoxide, (*b*) synthetic-oil ash mixture, and (*c*) 90-10 $V_2O_5$-$Na_2SO_4$ mixture. In no case did the service-type sulphide attack occur. (It is, however, recorded that later tests with an $Na_2SO_4$-$V_2O_5$ of reversed 90-10 composition have resulted in sulphur absorption, with some visible penetration of a type rather similar to that found in the sulphide-chloride mixture.)

With Nimonic 80A, alkali-salt mixtures were found to be particularly dangerous: on F.C.B. (T) steel (18-12 chromium-nickel type) calcium salts had a more serious effect, and 337 steel (17-17 chromium-nickel type containing small amounts of molybdenum and copper) was severely attacked by both classes of corrodent. The more general effects of composition were somewhat complicated. In steels chromium has a protective action against alkali salts, but it gives little protection against calcium salts. In alkali-salt mixtures high-nickel-chromium alloys show a resistance inferior to that of the individual metals, but the resistance of the alloys to calcium salts is better than that of their constituent metals.

The sulphate-chloride type of attack increases rapidly from 650° to 750°C. The probability of a breakdown in a limited time also increases with temperature in the 700°-800°C. range.

Availability of the dangerous salt mixtures at the metal surface is a feature of practical importance. There is indication that, in the absence of erosion, the large amount of alkaline-earth sulphates and inert materials present in the peat ash can have a very useful 'blanketing' effect against the arrival of fresh supplies of chloride and alkali salts.

The presence of unburnt carbon in peat ash at 750°C. caused some increase in attack on the steels, but not on Nimonic 80A. It is probably not a cause of severe attack in service.

Some structurally selective penetration of attack occurred in the salt mixtures, but no serious embrittlement was associated with this change, even in severely affected specimens.

An appendix to the paper gives details of technique used for removal of bulk oxide from the high-alloy materials.

### Chi Phase in Austenitic Steels

J. BIRTALAN and R. A. BLOOM: 'Occurrence of Chi Phase in a 16% Cr- 15% Ni- 7% Mn- 6% Mo Alloy.' *Jnl. of Metals*, 1956, vol. 8, Feb., Sect. II; *Trans. Amer. Inst. Mining and Metallurgical Engineers*, pp. 210-11; T.N. 295E.

This note describes laboratory examination of a phase observed (but then unidentified) in a high-manganese austenitic steel on which a report was published in *Trans. Amer. Soc. Metals*, 1954, vol. 46, pp. 1039-45. The observations made are correlated with reports by other investigators who have published data on the chi phase.

### Chromium-Nickel-Manganese Stainless Steels

R. A. LULA and W. G. RENSHAW: 'Corrosion-Resistance and Mechanical Properties of Chromium-Nickel-Manganese Stainless Steels.'

*Metal Progress*, 1956, vol. 69, Feb., pp. 73-7.

The authors of this paper are associated with Allegheny Ludlum Steel Corporation, which has been actively engaged for some years past in development of high-manganese stainless steels.

Two grades of these steels (designated 201 and 202) have been thoroughly evaluated in the laboratory, and are now in limited use in applications in which they can suitably replace higher-nickel corrosion-resisting steels. Two lower-carbon grades have also been developed, to which the designations 204 and 204L have been assigned, and a higher-chromium composition is in the experimental stage. Details of composition of all five modifications are given in the table below.

Graphs showing the mechanical properties of grades 201 and 202 are reproduced in the paper. (The mechanical properties of types 204, 204L and 22-6-8 are not illustrated, since they are very similar to those of type 202.) Type 201 steel (like its counterpart in the chromium-nickel series, type 301) is characterized by high tensile strength and a high

| A.I.S.I. Type | Designation | C % | Mn % | Cr % | Ni % | N % |
|---|---|---|---|---|---|---|
| 201 | 17-4-6 | 0·15 max. | 5·50- 7·50 | 16·0-18·0 | 3·50-5·50 | 0·25 max. |
| 202 | 18-5-8 | 0·15 max. | 7·50-10·00 | 17·0-19·0 | 4·00-6·00 | 0·25 max. |
| — | 204 | 0·10 max. | 7·50-10·00 | 17·0-19·0 | 4·00-6·00 | 0·25 max. |
| — | 204L | 0·06 max. | 7·50-10·00 | 17·0-19·0 | 4·00-6·00 | 0·25 max. |
| — | 20-6-8* | 0·10 max. | 7·00- 9·00 | 19·0-21·0 | 5·00-7·00 | 0·20-0·35 |

* Experimental

rate of work-hardening, resulting from the partial transformation of austenite to martensite. Type 202 is more stable, and its behaviour is closely similar to that of the chromium-nickel steel Type 302. Elongations of Types 201 and 202 are approximately equal to those of Types 301 and 302, respectively.

Experience in fabrication of the high-manganese steels indicates that tooling and forming practices employed for corresponding grades of chromium-nickel steel can be used for the modified types, and conventional methods of welding applied to the austenitic chromium-nickel steel are suitable for the high-manganese grades.

Comparison has been made of the higher-manganese lower-nickel steels with the standard chromium-nickel types on the basis of resistance to salt spray and to nitric acid, including behaviour under the boiling-nitric-acid test for susceptibility to intergranular corrosion after sensitizing. The results are considered by the authors to justify the following conclusions:—

The corrosion-resistance of chromium-nickel-manganese steels is superior to that of chromium-manganese steels containing little or no nickel. Types 201 and 202 show adequate corrosion-resistance in atmospheric environments and in many of the corrosive media in which the chromium-nickel steels 301 and 302 are now used. For severe conditions, such as those met with in the chemical industry, where Type 304 chromium-nickel steel is now used, the experimental manganese-containing type 20-6-8 appears to be satisfactory. This steel shows better resistance to localized attack than is shown by Type 201 and 202, or by nickel-free chromium-manganese steels. It is stated that after sensitizing for a short period the chromium-nickel-manganese steels are less susceptible to intergranular corrosion than is a Type 304 steel of equal carbon content, and it is claimed that an E.L.C. chromium-nickel-manganese steel would not require a carbon limit so low as the 0·03 per cent. maximum necessary in the chromium-nickel type.

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E. V. BENNETT: 'Staff Study on Low-Nickel Austenitic Stainless Steels.'

*Materials Advisory Board Report* MAB-45-SM, issued by the *Division of Engineering and Industrial Research, National Academy of Sciences, National Research Council, Washington, D.C.*, June 10, 1955; *Reprint*, Jan. 23, 1956; 30 pp. + appendix.

This is the full form of the report from which material was taken for the review on high-manganese stainless steels published by *Metal Progress*, December, 1955; see *Nickel Bulletin*, 1956, vol. 29, No. 3, p. 53.

### Rare Earths (Mischmetall) in Stainless Steel

H. O. BEAVER and B. T. LANPHIER: 'Rare-Earth Stainless Steels.'

*Materials and Methods*, 1956, vol. 43, Feb., pp. 96-8.

Papers previously published have reported higher yields in stainless steel and improved hot-working properties resulting from use of rare-earth additions in stainless steels of various types (see, for example, papers abstracted in *Nickel Bulletin*, 1954, vol. 27, Nos. 3 and 9, pp. 50, 175; 1955, vol. 28, No. 2, p. 34.)

This later report refers to specific applications in which such additions have proved beneficial.

(1) A complex acid-resisting steel had been available previously only in cast form (as Durimet 20). Treatment with Mischmetall has made possible the development of a wrought product (Carpenter Stainless No. 20), thus widening the applications of the material. As a demonstration of the corrosion-resisting characteristics of this steel, data are given on its behaviour in sulphuric-acid solutions of various concentrations, and at various temperatures. Comparison with the corrosion loss suffered by molybdenum-containing 18-8 chromium-nickel steel indicates the superiority of the Mischmetall-treated higher-alloy type.

(2) A further example of new alloy development is a rare-earth modification of a nitrogen-containing 21-12 chromium-nickel steel, used for valves, in which hot forgeability has been improved, by the addition of Mischmetall, to the extent that the valves can now be produced without difficulty. The better hot-working properties of the modified steel are illustrated.

(3) Tests on austenitic steel of the 25-20 chromium-nickel type have shown that a Mischmetall addition of the order of 4 lbs. per ton improves high-temperature strength and ductility, raising the stress-rupture properties by a factor of 25 per cent. at the 100-hour life level.

(4) The economic benefit resulting from the improved fabricating qualities conferred by rare-earth additions has been proved, for example, on steels of the 25-20 type, where Mischmetall not only improves forgeability but also substantially widens the forging-temperature range. This type of steel is considered to be forgeable in the range 1900°-2000°F. (1035°-1095°C.) but if forged at 2100°-2200°F. (1150°-1205°C.) it shows signs of over-heating and of edge cracking. Treatment with Mischmetall, however, provides a steel which shows excellent forging properties over the whole range 1900°-2200°F. (1035°-1205°C.).

### Changes in Surface Structure of Austenitic Steel by Mechanical Working

S. YAMAGUCHI: 'Examination of Stainless Steels by Electron Diffraction.'

*Zeitsch. f. Metallkunde*, 1956, vol. 47, Feb., pp. 95-6.

This brief note reports a study, by electron diffraction, of the transformation occurring in the surface layers of austenitic 18-8 chromium-nickel steel under the action of mechanical polishing or grinding. After such treatment the surface may consist of a mixture of austenitic and ferritic areas, which will give rise to formation of local elements, with resultant corrosion. The ferritic layers can be removed by electropolishing.

**Free-Machining Stainless Steel**

SOC. AUTOMOTIVE ENGINEERS: 'Steel: Corrosion-Resistant, 18 Cr-9 Ni (S.A.E. 30303F.), Free-Machining, High Yield Strength.'

*A.M.S. Specification* 5738, issued Feb. 1, 1956.

Covering cold-drawn bars for parts such as bolts, in which high strength is required, on which the amount of machining calls for a free-machining type of steel, and in which corrosion resistance similar to that of 18-8 chromium-nickel steel is desirable. The material is intended for parts not subjected to temperatures exceeding 700°F. (370°C.).

*Composition*, %: Carbon 0·12 max., silicon 1.00 max., manganese 0·20–2·00, sulphur 0·10 max., phosphorus 0·17 max., chromium 17·00–19·00, nickel 8·00–10·00, molybdenum 0·75 max., selenium 0·15–0·35, copper 0·50 max. Substitution of zirconium for molybdenum is optional with the manufacturer.

Tensile properties are specified for four different ranges of nominal diameter or distance between parallel sides.

**Stress-Corrosion Cracking of Austenitic Chromium-Nickel Steels**

T. P. HOAR and J. G. HINES: 'The Stress-Corrosion Cracking of Austenitic Stainless Steels.'

*Jnl. Iron and Steel Inst.*, 1956, vol. 182, Feb., pp. 124–43.

The work described is part of a programme of research into the fundamental mechanism of stress corrosion, in progress in the Department of Metallurgy, University of Cambridge. A short note on this work was published by the same authors in 1954 (*ibid.*, vol. 177, p. 248: see *Nickel Bulletin*, 1954, vol. 27, Nos. 7–8, p. 153).

It is pointed out that stress-corrosion cracking in austenitic steels may be either essentially intergranular or transgranular. Intergranular cracking appears to be associated with carbide precipitation, and can be avoided by the use of suitable steels or by appropriate heat-treatments. This type of cracking may occur in conditions which lead to intergranular corrosion in the absence of stress: stress appears merely to accelerate failure. For the occurrence of transgranular cracking, however, the presence of stress is a necessary condition. It is with the second type that the present paper is concerned.

The report opens with a review of work which has been carried out, by various investigators, to determine the conditions in which stress-corrosion cracking of austenitic steels can occur, and of methods of tests which have been employed to assess susceptibility. A critical evaluation is made of the usefulness of results obtained from specimens tested under constant direct load and from those in which some stress-relief takes place during exposure to the corrodent, e.g., bend-test specimens. In the research reported in this paper the specimens were wires stressed in tension while immersed in hot concentrated aqueous magnesium-chloride solution. An illustrated description is given of the test set-up, which allowed measurement of corrosion potential as well as of extension of the specimens during test. The magnesium-chloride solution was adopted as the basic corrodent because (*a*) it causes cracking of all austenitic steels under stress, and (*b*) it gives rapid and reasonably reproducible results. It is emphasized, however, that, in the authors' opinion, results obtained in such solutions on different materials cannot safely be used to assess the relative general susceptibility of these materials to stress-corrosion cracking: the conditions provide neither a true accelerated test nor a test of an inherent property of the materials. Such exposure provides, however, a convenient experimental means of studying the mechanism of a particular case of stress-corrosion cracking, within a reasonable time.

The wires used were representative of several generally used types of '18-8' chromium-nickel steel. The experiments were made in four main groups:—

(1) Preliminary evaluation of the suitability and capability of the apparatus, and measurement of times-to-fracture, by stress-corrosion cracking, of the various steels.

(2) Measurement of the variation of the corrosion potential of specimens exposed to stress-corrosion conditions, and correlation of this potential with the progress of stress-corrosion cracking as shown by mechanical tests.

(3) Study of the influence of variations in the experimental conditions (temperature, applied stress, presence of a surface oxide film, composition of the corrodent), on the resistance of the steels to stress-corrosion cracking, on the potential/time curves, and on the nature of the cracking.

(4) Metallographic examination of cracked specimens.

Much detailed information is given on the results obtained in all four sets of experiments. Correlation of all the observations made leads to conclusions which are summarized as follows:—

'(1) The stress-corrosion cracking of 18-8-type chromium-nickel steels in hot aqueous magnesium-chloride solutions takes place in stages, which may be demonstrated by following the electrode potential and the mechanical properties of steel specimens during the stress-corrosion cracking process.There is an induction period of corrosion damage, not greatly influenced by the presence of applied stress or by its value, followed by the initiation of cracks at points on the bared metal surface and their rapid propagation, roughly perpendicular to the greatest resolved tensile stress.

'(2) The induction period includes a period of oxide-film repair and may also include a period of film breakdown and pitting corrosion. In 42 per cent. w/w aqueous $MgCl_2$ at 154°C. it is of the order of 20–200 minutes for 'softened' 18-8 steels (slightly cold-worked in handling), stressed to 40,000–50,000 p.s.i. (17·85–22·3 tons per sq. in.). It is slightly shortened at higher applied stresses, and much lengthened at lower stresses. It is considerably shortened by increase of temperature over the range

135°–155°C. It is shortened to a few seconds by the acidification of the corrosive medium with 0·02 per cent. hydrochloric acid (which removes the initial oxide film) and is indefinitely lengthened by mild cathodic protection.

'(3) There is evidence that cracks are not initiated at 'stress-raising' corrosion pits, but rather that they begin at points on the bared metal surface that are especially anodically active.

'(4) Cracks are propagated at a rate of some 0·5–3·0 mm./h. This rate is somewhat enhanced by increase of temperature, but is almost independent of applied stress over a wide range. Cracking can be arrested by cathodic protection applied *after* it has begun: consequently, it involves electrochemical anodic dissolution. Although the extension of direct-loaded specimens while they are cracking is discontinuous, there is no evidence that crack propagation itself is discontinuous: the experimental evidence is consistent with propagation by the continuous anodic dissolution of the highly stressed and strained metal at the edge of the crack, advancing on a front up to 1000 Å wide, with concomitant anodic passivation of the unstressed fractured sides of the crack.

'(5) It is unlikely that practical problems of stress-corrosion cracking of 18–8-type chromium-nickel steels can be solved by attention to alloy composition, by heat, mechanical, or surface treatments, or by minimizing applied stress. On the other hand, means of reducing the corrosion damage, especially cathodic protection, appear to offer considerable promise.'

**Stainless Steel in Railway Engineering**

'Stainless Steels Guard Light-Weight Train.'
*Materials and Methods*, 1956, vol. 43, Feb., p. 95.

A set of photographs illustrates some of the uses made of stainless steel in a new light-weight train recently put into service in the U.S.A. Two of the new 40-passenger coaches together weigh 30 tons, as compared with a weight of 65 tons for one conventional 80-passenger coach.

The lower sections of the coaches are covered with stainless steel, and other uses of the same material include kick plates for entrances, and baggage compartments under the seats. The coaches were constructed by General Motors Corporation.

**Spring Materials: Specifications and Applications**

See abstract on p. 84.

**Corrosion by Fertilizers**

'The Problems of Corrosion by Fertilizers.'
*Proc. Fertilizers Soc.*, 1955, No. 32, pp. 3–60.

Report of papers and discussion presented at Joint Conference between The Fertilizer Society and The Institution of British Agricultural Engineers, London, Apr. 21, 1955.

Introductory remarks by the President of The Fertilizer Society, MR. J. T. PROCTOR, were followed by the papers shown below:—

W. D. CLARK: 'The Chemistry and Metallurgy of Corrosion of Metals by Fertilizer Materials', pp. 4–22; disc., pp. 22–3.

A general survey, dealing with the importance of corrosion as an economic factor, the theory of corrosion processes, and the types of corrosion which may be encountered, the resistance of ferrous and non-ferrous materials to corrosion attack, and the nature of the attack involved in the use of typical fertilizing media.

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J. E. NICHOLSON: 'Methods Used by Manufacturers to Reduce the Corrosive Effect of Fertilizers on Fertilizer-Distributing Machines', pp. 24–7; disc., pp. 27–30.

Based on observations made during tests of the resistance of various steels, cast iron and non-ferrous materials to representative fertilizers, three possible methods which may be adopted to reduce corrosion of distributors are considered, *viz.*:—

(1) use of a corrosion-resisting material, e.g., stainless steel,

(2) use of less expensive metals, protected by coatings,

(3) disregard of corrosion-resistance of materials from which the distributors are made, but adoption of design such that the machines may be easily cleaned, thus eliminating the basic cause of the corrosion.

Critical discussion of these alternatives leads to the conclusion that (1) is ruled out by cost, (2) is unsatisfactory, due to wearing away of the protective coatings during service, (3) offers the best solution. Correct design, good maintenance and the use of inexpensive materials will ensure satisfactory service over a reasonable period and replacement with a minimum of cost.

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C. R. PIPE: 'The Corrosion of Steels in Relation to Fertilizer Chemicals', pp. 31–48; disc., pp. 48–9.

Conditions necessary for initiation and continuation of corrosion are defined: (1) presence of moisture, (2) wetting of the metallic surface, (3) presence of dissolved salts or gases, and (4) development of an electrolytic cell. The occurrence of these conditions as associated with use of fertilizers is then considered, and the degree of resistance to attack offered by various types of steel is discussed, with due regard to (*a*) their technical suitability and (*b*) the economic factors involved in their use. On this basis consideration is given to plain carbon, low-alloy high-strength, chromium, and austenitic chromium-nickel steels: the wide range of corrosion-resistance offered by the last-named group is indicated, but due regard is paid to the relatively heavy initial cost of equipment in stainless steel. The importance of correct design is urged, with particular reference to avoidance of any possibility of lodgement of fertilizer compounds at spots inaccessible for cleaning, and to the importance of providing ample facilities for draining out during flushing.

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R. PATERSON: 'Fertilizer Distribution: Problems of Corrosion Prevention on the Farm', pp. 50–5; disc., pp. 55–9.

This paper is based on experience on a farm on which fertilizer distributors of various kinds are used, and also combined grain- and fertilizer-drills. Complete fertilizers containing nitrogen, phosphate and potash, and also 'Nitro-chalk', are the media handled. The author makes practical recommendations with regard to cleaning and protective coating of distributor parts, and design. He also suggests aspects of fertilizer distribution on which further research is required.

**Metallurgical Factors in the Welding of Stainless and Other Steels**

M. C. T. BYSTRAM: 'Some Aspects of Stainless Alloy Metallurgy and Their Application to Welding Problems.'

*Brit. Welding Jnl.*, 1956, vol. 3, Feb., pp. 41–6.

The metallurgical aspects involved in the welding of the austenitic stainless steels are studied in relation to the fabrication of equipment for either low- or high-temperature service.

The effects of the usual alloying elements, in promoting in steels the formation of ferrite, martensite or austenite, is summarized in the characteristic manner from the Schaeffler diagram. The diagram is then used to show the expected metallographic structures of some typical austenitic stainless-steel groups, and of a 5 per cent. chromium, $\frac{1}{2}$ per cent. molybdenum steel, with particular reference to weld-metal compositions. The three types of potential weld defects, (*a*) hot cracking, (*b*) martensitic cracking, and (*c*) sigma phase and embrittlement, are then considered, in relation to the nature of the weld metal. The final composition of the weld is deduced from the dilution of the weld deposit by the fused parent material, again using the Schaeffler diagram. The value of the diagram is also emphasized when selecting the composition required in a particular electrode designed to obviate cracking when joints are made between similar or dissimilar materials.

The merits of a weld deposit containing a small but controlled amount of ferrite, in minimizing the effects of hot cracking, are studied, together with the associated risk of sigma formation. The possibility of martensitic cracking is considered in relation to the chromium-molybdenum steel. In discussing these cracking risks, some useful information is given on actual welding technique, e.g., controlling the composition of the weld metal and minimizing the stress in the joint.

The author concludes with a note on the impact value of austenitic weld metal at sub-zero temperatures, demonstrating the influence of ferrite. Mention is made of the fact that welded austenitic steels show no brittle transition temperature, although the impact resistance of the weld is usually somewhat lower than that of the parent material.

**Welding of Nickel-Alloy Pump Parts in Atomic-Energy Plant**

E. NUTTER: 'Cold Welding Nickel Alloys for Atom Plant Use.'

*Iron Age*, 1956, vol. 177, Feb. 16, pp. 111–13.

The author gives a step-by-step account of technique which has been developed (by Elano Corporation, Xenia, Ohio) for welding components of centrifugal pumps constructed from nickel alloys. (No details of the composition of alloys are given.)

Inert-gas arc welding is exclusively used: argon is the preferred protective medium. The penetration characteristics of the alloys are such that it is found desirable to use low heat input: multiple passes, with $\frac{3}{32}$-in. diameter rods, are employed, and a typical weld may take approximately 40 passes to build up two inches of weld metal. The low operating temperature of the multiple-pass, narrow-bead welding method results in only slight grain growth in the fringe area of the parent metal, and also ensures a uniform structure in the weld metal as it builds up. The final result is a strong, ductile, and sound weld, which has mechanical properties closely approximating those of a cold-drawn nickel-alloy rod. In addition, corrosion-resistance in the weld area is equal to that of the parent metal.

Conditions of absolute cleanliness are an essential feature of the process: means adopted to ensure such conditions are described. After each bead is laid down it is carefully checked for soundness, by the liquid-penetrant-dye method, and this test is repeated in some joint areas as many as 40 times, until the required amount of weld metal has been built up.

In order to meet specifications dictated by service-life requirements, each unit is given a stabilization heat-treatment at 1500°F. (815°C.), and to protect the metal surface from oxidation, and also to retard intergranular corrosion, an inert atmosphere of inert helium and hydrogen surrounds the parts throughout 40-hour heat-treatment cycle.

After final machining, the welded assemblies are tested for leakage: they are heated to 250°F. (120°C.) and put under an internal pressure of Freon gas at 5 p.s.i.

**Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.**



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